

Article

Hamstring Injuries in MLB Are Not Lateralized to the Throwing Arm or Inside Leg: An Analysis of 1435 In-Game Injuries (2011–2017)

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Abstract

Hamstring injuries in professional baseball remain incompletely understood related to laterality in being either ipsilateral or contralateral to the throwing arm. General and specific injury comparisons were investigated with respect to independent lower-limb, environmental conditions, position, throwing arm side relationship, and age. More left and non-dominant-sided hamstring injuries were hypothesized in baserunning with greater injury presence in infielders and younger players. Between 2011 and 2017, 1435 hamstring injuries were identified within the major league baseball Health and Injury Tracking System. Data included laterality (left versus right, contralateral versus ipsilateral to the throwing arm), position, time of season, days missed, mechanism of injury, and age. Chi-Square, *t*-tests and Mann–Whitney U tests evaluated significant findings with an a priori of $p < 0.05$. No significant differences in injury laterality (right vs. left) with baserunning ($p = 0.797$) or in total ($p = 0.367$) or contralateral vs. ipsilateral injury laterality in total ($p = 0.770$) were seen. No significant laterality differences were seen by position, days missed, or time in the season. In general, most injuries occurred in the first half of the season (67.8%, 973/1435). Outfielders were the most injured position (34%, 495/1435). Athletes under 25 years were the most injured age group as compared to the 30–34 group ($p = 0.037$), 35–39 group ($p = 0.038$), and the 40+ group ($p = 0.024$). No statistically significant hamstring injury asymmetries were identified among major league baseball players despite biomechanical theories suggesting potential differences in lower-limb loading during baseball activities. Younger athletes demonstrated greater injury susceptibility, highlighting the need for future investigation into factors that may contribute to elevated injury incidence in younger professional baseball players.



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1. Introduction

Injury rates in professional baseball players have been increasing over the last decade. A recent study by Camp et al. reported a total of 49,955 injuries between 2011 and 2016 in professional baseball players, both major and minor league, that resulted in

722,176 days missed [1]. The most common injury sustained by professional baseball players in this study was to the hamstring and thus these injuries are among the most important in professional baseball [1]. There was a total of 3337 hamstring injuries among these players that led to 46,706 days missed, with an average number of days missed per injury of 14.5 days. The authors found that most of these injuries were first time injuries (97.4%) and were acute (76.9%) [1].

One aspect of hamstring injuries that has not been well studied in professional baseball players is the side (laterality; right vs. left, contralateral vs. ipsilateral to the throwing arm) of hamstring injuries. Previous work indicated that biceps femoris injuries in baseball players were most common in baserunning, yet no insights were provided in relation to differences in injury susceptibility between the inside leg (left side) nor outside leg (right side) with respect to sprinting around the bases for position players [2]. Biomechanical assessment of curvilinear sprinting elucidates the potential overload of the inside leg (left leg) in curvilinear sprinting. Baseball baserunning differs from continuous curvilinear sprinting models in other sports due to unique field geometry with bases placed at 90-foot distances, intermittent acceleration patterns, and dirt playing surfaces. Motion analyses revealed longer ground contact times for the inside leg on curves (potentially lowering impulse) while the outside leg experiences shorter ground contact times that are associated with increased biceps femoris electrical activity, yet scarce evidence exists to reveal lateral hamstring injury tendencies in position players [3]. Greater left leg joint moments were seen for the ankle in plantar flexion, hip adduction, as well as hip flexion during the propulsive phase when analyzing curvilinear sprinting gait [4]. Although energy generation occurred in the sagittal plane, compared to straight line sprinting, the left ankle had to absorb greater energy in transverse and mediolateral directions. Therefore, a change in ankle stabilization may alter joint moments and velocities, and consequently, altered energy flow for the left hip and knee could have injurious consequences for the left hamstring [4]. Furthermore, biomechanical traits in other work presented clear differences between straight line and curved sprinting at 30 m, as increased lateral body lean at left foot touchdown into the radius of the curve could increase loading on the inside left leg through increased hip adduction and external rotation to negotiate the centripetal effects of the trunk mass [5].

Although sprint biomechanical analyses point to greater risk of injury to the left leg, in pitching, prior studies have found the hamstrings from the drive leg to be more active in professional baseball pitchers than the landing leg [6]. These data suggest that there should be an asymmetry in hamstring laterality distribution, yet despite differences in lower-limb electromyography, there is limited evidence on side of hamstring injury both in pitchers as well as position players. Furthermore, it is unclear if age plays a role in the risk of hamstring injury, or the lateralization of hamstring injuries in professional baseball players. As injury prevention programs gain more acceptance and traction, it is important to better understand injury surveillance data so that these prevention programs can target the correct population to make a noticeable difference in injury rates.

Therefore, the purpose of this study was to determine whether hamstring injuries are evenly distributed between sides, in general and specifically among baserunning injuries. Secondary purposes were to determine whether hamstring injury laterality differs in position, side of arm dominance, and days missed, and to determine whether hamstring injuries are evenly distributed amongst positions and age groups. The authors hypothesized that more left and non-dominant-sided hamstring injuries would occur during baserunning due to potential asymmetrical loading patterns associated with baseball movement demands. The authors further hypothesized that younger athletes and infielders may demonstrate greater injury incidence due to positional and workload demands.

2. Methods

This study was performed with the approval of the Major League Baseball (MLB) Research Committee involving de-identified data and exempt from the IRB approval process. All professional baseball players who sustained a hamstring injury between 2011 and 2017 were eligible for inclusion. Study data were analyzed from the MLB Health and Injury Tracking System (HITS) database. HITS is a centralized database that contains de-identified player information and was developed as a league-wide injury surveillance system in 2010 to record player injuries and injury time [7]. HITS has been used in several prior studies and has been found to be a reliable source of information [1,8]. We included the 2011–2017 seasons. Because the study was specifically of in-game mechanisms of injury, only those injuries that were categorized as occurring within a game were included. Within the database, each injury is categorized using the Sport Medicine Diagnostic Coding System (SMDCS) and classified using a free-text event description. Those patients with an SMDCS designation of either a hamstring strain, hamstring spasm, or hamstring tear/rupture were included as they resulted in lost playing time. Those patients categorized via SMDCS as “Other Thigh Injury”, “Other Hip Injury”, “Other Knee Injury”, or “Other Leg Muscle Strain” with a free-text description of a hamstring strain, spasm, or tear/rupture were also included as these injuries caused lost playing time. In total, this included 1442 injuries, seven of which were excluded as they were bilateral injuries documented on the same record, for a total of 1435 injuries included. These 1435 injuries occurred in 1022 players.

The following data were available for each injury: date of injury, position, dominant side for throwing, laterality of injury, height, weight, age, number of days missed due to injury, the activity the player was engaged in at the time of injury, the mechanism of injury, and the level of play (major vs. minor league) at the time of injury. Based upon these, each injury was categorized as ipsilateral, i.e., occurring on the dominant throwing side, or contralateral, i.e., occurring on the side opposite to the dominant throwing side. For switch hitters and two-way players, the affected limb was referenced related to the dominant throwing side as mentioned previously. To further illustrate, if a player was right-handed in throwing but hit left-handed, an injury record indicating the left hamstring would still be considered contralateral, even though the leg is dominant side for the hitting. As it relates to position designations, players listed as infielders (IFs) are players who play a variety of positions across the infield, and if players were listed as outfielders (OFs) on their medical record, that means they play a combination of outfield positions and not a singular outfield position. Athletes were categorized in only one designation only and not counted across a combination of positional designations. Therefore, if a player was listed as a second baseman, he would not be counted in the IF designation as well. There were no switch throwing athletes in the dataset. Total games represented cumulative player–game exposure counts for each age and positional grouping across the study period. For specific injury comparisons, the total number of in-season and post-season games played during the study period in major and minor league baseball for each position and age group (<25, 25–29, 30–34, 35–39, 40+) were determined and calculated as injury incidences that evaluated injury prevalence between positions and age groups.

Statistics

All analyses were performed in Excel 16 (Microsoft, Redmond, WA, USA) and SPSS 26 (IBM, Armonk, NY, USA). Categorical variables were compared using Chi-Square tests and continuous variables were compared using student’s *t*-tests and Mann–Whitney *U* tests as appropriate based upon data normality as determined based upon the results of the Kolmogorov–Smirnov test. The level of statistical significance for our *p*-values was set at 0.05. Age and position groups were compared using an analysis of variance with

post hoc Tukey's testing. Given the exploratory epidemiologic design and retrospective nature of the investigation, findings were interpreted cautiously with emphasis placed on effect size interpretation in conjunction with statistical significance testing. Effect sizes were calculated to supplement null hypothesis significance testing and provide interpretation of the practical magnitude of observed differences. The eta squared (η^2) was calculated for group ANOVA models to estimate the proportion of variance explained at the age and position level, while Cohen's *d* effect sizes were computed for significant post hoc pairwise comparisons. The eta squared (η^2) was calculated as the ratio of between-group sum of squares to total sum of squares from the ANOVA model. Because injury incidence was evaluated across a limited number of age categories with substantial between-group differences, η^2 values may appear larger than those commonly observed in biomechanical investigations evaluating continuous performance variables. Because injury incidence rates demonstrated substantial separation between age cohorts despite a limited number of categorical groupings, η^2 values should be interpreted as estimates of explained variance across grouped epidemiologic data rather than direct indicators of clinical magnitude or injury risk. Effect size interpretations were based on commonly accepted thresholds. For η^2 , values of 0.01, 0.06, and 0.14 were interpreted as small, moderate, and large effects, respectively. For Cohen's *d*, values of 0.20, 0.50, and 0.80 were interpreted as small, moderate, and large effects, respectively, between cohorts. Reporting effect sizes alongside *p*-values was intended to provide greater context regarding the practical and clinical relevance of observed findings.

3. Results

Among the included injuries, most were in position players (84%, 1211/1435, Table 1) with outfield being the most common position (34%, 495/1435). There were no differences in distribution of left- vs. right-sided injuries between positions ($p = 0.830$) and there were no differences in ipsilateral vs. contralateral injuries between positions ($p = 0.918$). Most included players batted right-handed (73%, 1049/1435) and threw right-handed (85%, 1226/1435). Left-sided injuries were non-significantly more common than the right-sided injuries (53.4%, 766/1435, $p = 0.367$). Contralateral injuries with respect to the throwing hand were more common than ipsilateral injuries (53.2%, 763/1435), and this distribution of sides did not differ from a distribution in which sides were randomly assigned ($p = 0.625$). Most injuries were related to baserunning (71.2%, 1022/1435, Table 2).

Table 1. (a). Distribution of right and left injury side within each position for all hamstring injuries. (b) Distribution of injury side with respect to throwing arm within each position for all hamstring injuries.

(a)		
Position	Side	
	L	R
1B	62% (49/79)	38% (30/79)
2B	51% (56/110)	49% (54/110)
3B	50% (59/117)	50% (58/117)
C	50% (63/126)	50% (63/126)
CF	49% (63/129)	51% (66/129)
DH	60% (3/5)	40% (2/5)
IF	48% (39/82)	52% (43/82)

Table 1. *Cont.*

LF	59% (20/34)	41% (14/34)
LHS	58% (15/26)	42% (11/26)
OF	40% (12/30)	60% (18/30)
RF	55% (148/270)	45% (122/270)
RHR	53% (33/62)	47% (29/62)
RHS	56% (35/62)	44% (27/62)
SS	60% (64/106)	40% (42/106)
UI	55% (102/185)	45% (83/185)
(b)		
	Side	
Position	CL	IL
1B	63% (50/79)	37% (29/79)
2B	51% (56/110)	49% (54/110)
3B	50% (59/117)	50% (58/117)
C	50% (63/126)	50% (63/126)
CF	55% (71/129)	45% (58/129)
DH	60% (3/5)	40% (2/5)
IF	49% (40/82)	51% (42/82)
LF	56% (19/34)	44% (15/34)
LHS	42% (11/26)	58% (15/26)
OF	60% (18/30)	40% (12/30)
RF	50% (135/270)	50% (135/270)
RHR	52% (32/62)	48% (30/62)
RHS	56% (35/62)	44% (27/62)
SS	60% (64/106)	40% (42/106)
UI	55% (102/185)	45% (83/185)

L = left; R = right; 1B = first base; 2B = second base; 3B = third base; C = catcher; CF = center field; DH = designated hitter; IF = infield; LF = left field; LHS = left-handed starter; OF = outfield; RF = right field; RHR = right-handed reliever; RHS = right-handed starter; SS = shortstop; UI = utility player. CL = contralateral to throwing arm; IL = ipsilateral to throwing arm.

Table 2. Injury activities.

Activity	% (N)
Baserunning	71.2% (1022/1435)
Batting	2.7% (39/1435)
Fielding/Throwing	15.3% (220/1435)
Pitching	9.3% (133/1435)
Other	1.5% (21/1435)

The distribution of injury mechanisms for hamstring strains in major league baseball from 2011 to 2017.

Among injuries related to baserunning, left-sided injuries were more common than right-sided injuries (51.5%, 526/1022, Table 3) and the distribution of sides did not differ from a distribution in which sides were randomly assigned ($p = 0.797$). Contralateral hamstring injuries to the throwing hand were more common than ipsilateral injuries (51.2%,

523/1022) among injuries related to baserunning and this distribution of sides did not differ from a distribution in which sides were randomly assigned ($p = 0.770$). More injuries occurred in the first half of the season prior to the All-Star Break (67.8%, 973/1435) than the second half of the season (31.6%, 454/1435), with post-season injuries being uncommon (0.06%, 8/1435). There were no differences in the distribution of right vs. left-sided injuries between times of year ($p = 0.391$), and there were no differences in the distribution of ipsilateral vs. contralateral between times of year ($p = 0.392$). Players missed 20 ± 36 days due to injury, with no differences between left (21 ± 39 days) and right (19 ± 31 days, $p = 0.941$) or between ipsilateral (20 ± 33 days) and contralateral (21 ± 38 , $p = 0.370$) to the throwing hand. When age groups were compared, there were significant differences (Table 4). Table 5 indicated large effects for ANOVA testing ($p = 0.017$, $\eta^2 = 0.529$). Although η^2 indicated that age group membership explained a substantial proportion of the variance in injury incidence, this finding should be interpreted cautiously because the effect size reflects differences across a limited number of categorical age cohorts and does not imply that age alone determines injury risk. Post hoc testing demonstrated significantly higher hamstring injury incidences in the <25 group compared to the 30–34 group ($p = 0.037$, $d = 1.45$), 35–39 group ($p = 0.038$, $d = 1.50$), and 40+ group ($p = 0.024$, $d = 1.60$), all representing large effect sizes. No significant differences were observed between position types ($p = 0.387$, $\eta^2 = 0.11$).

Table 3. (a) Distribution of injury side within each position within baserunning injuries. (b) Distribution of injury side with respect to throwing arm side within each position for baserunning injuries.

(a)		
	Side	
Position	L	R
1B	59% (38/64)	41% (26/64)
2B	49% (44/89)	51% (45/89)
3B	51% (44/87)	49% (43/87)
C	50% (54/109)	50% (55/109)
CF	46% (49/107)	54% (58/107)
DH	60% (3/5)	40% (2/5)
IF	42% (30/71)	58% (41/71)
LF	50% (13/26)	50% (13/26)
LHS	50% (3/6)	50% (3/6)
OF	55% (116/210)	45% (94/210)
RF	51% (24/47)	49% (23/47)
RHR	50% (7/14)	50% (7/14)
RHS	63% (12/19)	37% (7/19)
SS	54% (85/158)	46% (73/158)
UI	40% (4/10)	60% (6/10)

Table 3. *Cont.*

(b)		
Position	Side	
	CL	IL
1B	58% (37/64)	42% (27/64)
2B	49% (44/89)	51% (45/89)
3B	51% (44/87)	49% (43/87)
C	50% (54/109)	50% (55/109)
CF	56% (60/107)	44% (47/107)
DH	60% (3/5)	40% (2/5)
IF	44% (31/71)	56% (40/71)
LF	54% (14/26)	46% (12/26)
LHS	50% (3/6)	50% (3/6)
OF	48% (100/210)	52% (110/210)
RF	53% (25/47)	47% (22/47)
RHR	50% (7/14)	50% (7/14)
RHS	63% (12/19)	37% (7/19)
SS	54% (85/158)	46% (73/158)
UI	40% (4/10)	60% (6/10)

L = left; R = right; 1B = first base; 2B = second base; 3B = third base; C = catcher; CF = center field; DH = designated hitter; IF = infield; LF = left field; LHS = left-handed starter; OF = outfield; RF = right field; RHR = right-handed reliever; RHS = right-handed starter; SS = shortstop; UI = utility player. CL = contralateral to throwing arm; IL = ipsilateral to throwing arm.

Table 4. Injury incidences by age group and position type.

Age Group	Position	Total Games	# Hamstring Injuries	Hamstring Injuries/Game
20–24	DH	43,720	0	0.000
20–24	IF	24,760	336	0.014
20–24	OF	15,077	260	0.017
20–24	P	12,516	77	0.006
25–29	DH	168,704	0	0.000
25–29	IF	92,258	240	0.003
25–29	OF	58,128	154	0.003
25–29	P	71,850	90	0.001
30–34	DH	116,473	4	0.000
30–34	IF	61,718	103	0.002
30–34	OF	41,083	69	0.002
30–34	P	40,786	43	0.001
35–39	DH	31,028	1	0.000
35–39	IF	14,795	31	0.002
35–39	OF	8090	12	0.001
35–39	P	12,435	12	0.001

Table 4. Cont.

Age Group	Position	Total Games	# Hamstring Injuries	Hamstring Injuries/Game
40+	DH	3529	0	0.000
40+	IF	902	1	0.001
40+	OF	900	0	0.000
40+	P	1939	2	0.001

On ANOVA testing, there were significant differences between age groups ($p = 0.017$), with post hoc testing demonstrating significantly higher hamstring injury incidences in the <25 group than the 30–34 group ($p = 0.037$), the 35–39 group ($p = 0.038$), and the 40+ group ($p = 0.024$), with all other comparisons being non-significant. There were no significant differences between position types ($p = 0.387$, all post hoc tests non-significant). DH = designated hitter; IF = infield; OF = outfield; P = pitcher.

Table 5. Effect size comparisons across position and age designations.

Comparison	p -Value	Effect Size (η^2)	Interpretation	95% Confidence Interval
Overall Age Group ANOVA	0.017	0.529	Large	95% CI [0.12, 0.71]
<25 vs. 30–34	0.037	1.45	Large	95% CI [0.18, 2.72]
<25 vs. 35–39	0.038	1.50	Large	95% CI [0.21, 2.79]
<25 vs. 40+	0.024	1.60	Large	95% CI [0.28, 2.92]
Position-Type ANOVA	0.387	0.11	Small-to-moderate	95% CI [0.00, 0.29]

Large effects were seen amongst age categorizations after significance was reached in ANOVA testing ($p = 0.017$, $\eta^2 = 0.529$), with post hoc testing demonstrating significantly higher hamstring injury incidences in the <25 group than the 30–34 group ($p = 0.037$, $d = 1.45$), the 35–39 group ($p = 0.038$, $d = 1.50$), and the 40+ group ($p = 0.024$, $d = 1.60$), all representing large effect sizes. All other comparisons were non-significant. There were no significant differences between position types ($p = 0.387$, $\eta^2 = 0.11$).

4. Discussion

While hamstring injuries are extremely common in professional baseball players, the specifics of these injuries are still incompletely understood. No statistically significant hamstring injury asymmetries were identified among major league baseball players. This absence of detectable population-level laterality remains an important epidemiologic finding despite biomechanical theories suggesting asymmetrical lower-limb loading during baseball activities. Left-sided injuries did not result in more days missed than right-sided injuries. However, younger players were at higher risk of hamstring injuries, with outfielders being most at risk. The latter finding suggests that this group could be targeted with prevention strategies, which have been demonstrated to be effective for these injuries.

Within our study there were no asymmetries in laterality distribution. These results differ from previous research that reported contralateral hamstring injuries to be significantly more common in pitchers. Our results are similar in that severity of injury, as determined by injury list days, was not found different between sides [9]. Several factors may explain why our findings differ from prior studies. It is possible that these differences are driven by the demands of different positions included in the epidemiological sample that may have included more multidirectional rotation and change in direction in defensive situations to reduce overuse of the left leg.

Further research may support a statistically significant difference despite more left leg data entries in this work that resulted in 51% of hamstring injuries. Specifically, in position players, hamstring loading may be more varied with multidirectional movement when playing defense, balancing the risk between sides. Mechanistically, the reasons remain uncertain why curvilinear sprinting did not reveal greater risk, as previous research

shows greater ground impact with curved sprinting compared to linear sprinting that also entails asymmetrical loading of the lower limbs [10]. In the current study, lateralized injury risk was non-significant despite biomechanical and anatomical publications presenting significant differences in the role of each leg. Furthermore, the absence of statistically significant laterality differences should not be interpreted as evidence that biomechanical asymmetries do not exist, but rather that such asymmetries were not reflected in population-level injury distributions within this epidemiologic dataset. Thus, the thought process of the left leg being at greater risk remains theoretical and not substantiated by this work.

4.1. Biomechanical Considerations in Curvilinear Baseball Sprinting

Our findings opposed anticipated biomechanical strain mechanisms, as the data indicated the absence of greater inside-leg (left leg) hamstring injury prevalence. Reasons for this may relate to prior curvilinear sprinting research demonstrating greater outside-leg (right leg) impact magnitudes during turning maneuvers [10]. Anatomical analyses of curvilinear sprinting suggest that bilateral foot alignment and transverse and oblique foot axes play important roles in directing ground reaction forces during turning mechanics that impact lateralized injury risk [11]. During traditional baserunning, the outside foot (right foot) primarily uses the transverse axis to center pressure into the turn, whereas the inside foot (left foot) relies more heavily on the oblique axis to absorb force, resist excessive inward lean, and stabilize the center of mass throughout the curve [11]. Therefore, altered foot positioning for either leg may misalign direction of force that theoretically may increase torsional demands on the biceps femoris and hamstring musculature during touchdown through toe-off to expose both legs to risk. A detailed diagram of curvilinear baserunning and ground contact interaction with the inside and outside foot can be seen in Figure 1.

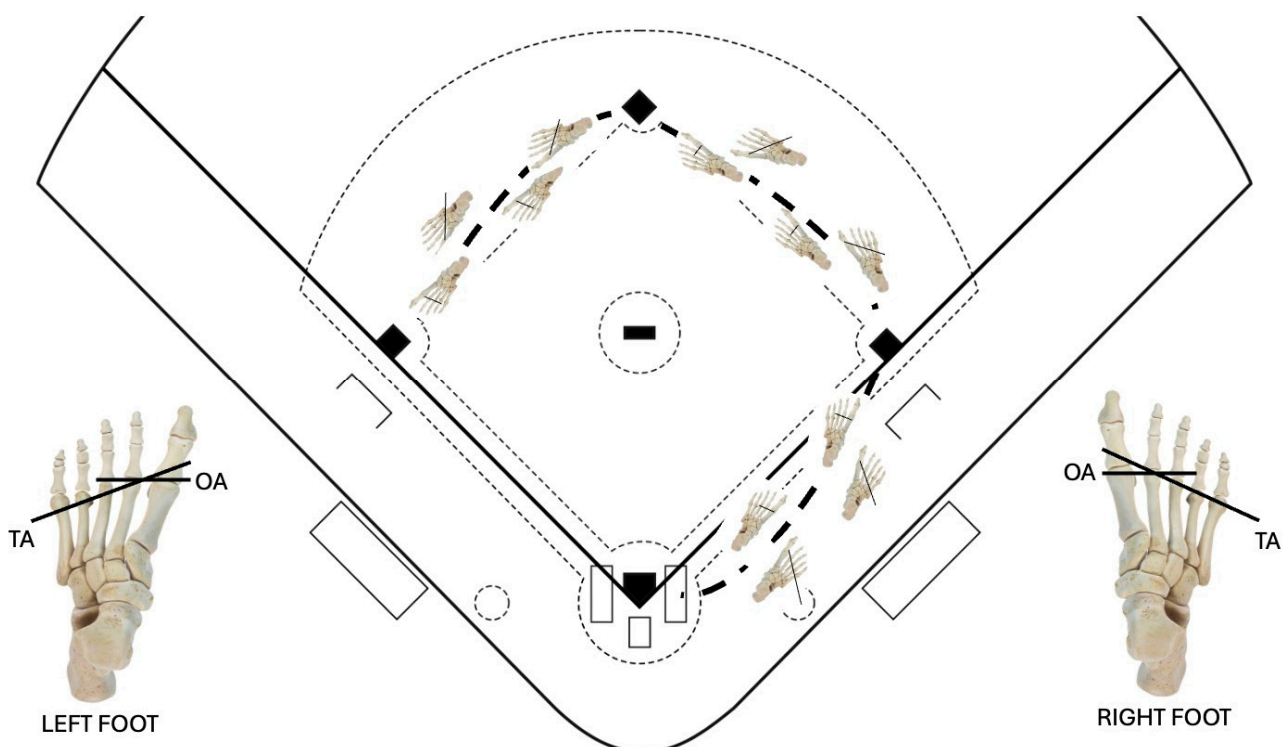


Figure 1. Schematic of curvilinear baserunning path in sprinting to reach third base on a triple. The bases are rounded in an anticlockwise direction, such as attempting to score a run and advancing to

two bases or more on a single play. The transverse axis of the right foot (angled lines on the feet) and oblique axis of the left foot (horizontal lines) direct forces into the turn. Oblique Axis of the Foot; OA, Transverse Axis of the Foot; TA. The thick solid dotted line indicates curvilinear path. Light dotted lines outline the infield with black squares representing the bases on the field. Alterations in foot position may influence lower-limb loading characteristics during curvilinear sprinting and warrant future biomechanical investigation.

We did not find any statistically significant differences in hamstring injury incidence per game between positions. Overall, more injuries were reported for outfielders in the current study, which differed from previous research that showed infielders to have greater total injuries and pitchers to have higher hamstring injury rates when accounting for player population [2]. Future investigations may evaluate whether workload characteristics and hamstring strength profiles differ among outfielders compared to other positions [12].

Our data illustrated that an athlete under the age of 25 had significantly higher injury incidence per game. Ahmad et al. [13] found equal hamstring injury rates between major league and minor league athletes, with slightly longer recovery times for minor league players that are likely to be younger. Comparatively, lower injury incidence found within the 40+ age group should be approached cautiously because of the relatively small number of players and games represented within this cohort. In future, injury surveillance research could reveal lessened risk and potentially greater strain resistance among younger players by studying how strength coaches progress athletes' training loads throughout biological and competitive development. It is hypothesized that disparities in training age (years of strength and conditioning experience), acute-to-chronic workload imbalances, ineffective offseason preparation, and running speed may be underlying influences for why younger athletes are at higher risk.

4.2. Potential Clinical and Performance Applications

Although not directly evaluated within the current investigation, clinical literature may provide future directions for hamstring injury prevention and athlete monitoring.

Hamstring injuries tend to occur prior to the All-Star Break. April and May have been shown to have the highest incidence of hamstring injuries which is consistent with our results [2,13]. Given that most injuries occurred prior to the All-Star Break, future investigations should examine whether preseason preparation strategies influence early-season injury incidence. Previous investigations have identified communication, workload progression, and preseason preparation as potential contributors to hamstring injury risk in professional baseball. Future research should evaluate whether offseason sprint exposure and preseason workload progression influence injury susceptibility [14]. Further, the literature points to the importance of a progressive plan that does not undertrain or overtrain athletes that could form conclusions whether offseason sprint exposure and preseason workload progression influence injury [14].

An MLB-wide survey was provided to sports medicine practitioners to obtain their opinions on why hamstring injuries are the most frequent injuries and the mechanisms related to injury rates [14]. Contrary to injury prevention standards, hamstring health was not routinely screened during the season despite it being the top injury factor in professional baseball [14]. Internal communication breakdown between initial hamstring strains and recurrent injury was considered a large factor, while compliance and lack of buy-in were mentioned as additional reasons that degrade efficacy of programming, as staff and coaches experience conflict in implementation. A key factor that may contribute to future injury after a first occurrence is the lack of individualization in programming as only 18% of respondents communicated a highly individualized approach to building stress tolerance rather than a common protocol. Modifiable approaches to rehabilitation and

early prevention to reduce hamstring injuries were core and lumbopelvic strengthening, exposure to high-speed sprinting, and eccentric-only training exercises.

4.3. Current Objective Screening Methods and Approach to Training Methodologies: Implications for Practice

Eccentric strength testing has been more commonplace for MLB teams, yet the frequency and approach to testing can vary [14,15]. Nordic hamstring testing may increase soreness and reduce athlete buy-in because of the eccentric loading demands involved [14,15]. One such approach to strengthening and testing is the Nordic hamstring exercise. Driggers et al. reported that athletes producing less than 377 N during Nordic hamstring testing demonstrated significantly greater injury risk, while interlimb asymmetry was not predictive of future injury [15]. The authors also identified reduced injury risk with greater absolute hamstring force production using both Nordic hamstring testing and a modified single-leg isometric bridge assessment, suggesting that improving absolute hamstring strength may help mitigate injury risk [15].

Although exercise selection and periodization strategies were not evaluated within the current investigation, the previous literature suggests that different hamstring training modalities may influence muscle recruitment patterns and strength adaptations. Nordic hamstring exercises have demonstrated injury prevention efficacy in several athletic populations, while hip-dominant exercises such as the Romanian deadlift may preferentially recruit the biceps [16,17]. Because biceps femoris injuries are common in baseball, future investigations should evaluate whether exercise selection influences injury risk, performance outcomes, or adaptation profiles in baseball athletes [16], as efficacy could be empirically studied comparing hip-dominant to knee-dominant hamstring training methods. Future investigations may evaluate whether hip-dominant and knee-dominant hamstring training approaches produce different adaptations relevant to baseball performance and injury risk to combat aggressive acceleration, deceleration, and torsional forces observed during baserunning and curvilinear sprinting [11,16]. With access to training records through team strength and conditioning departments, such determinations governing injury protection between exercise selections may be realized. Similarly, another suggested research direction would be the exploration of bilateral versus unilateral exercise exposure to determine impacts on injury reduction. Given the unilateral nature of pitching, hitting, baserunning, and defensive play, future studies may evaluate whether unilateral and bilateral training exposures differentially influence injury risk, performance adaptation, or asymmetry development in baseball athletes [18]. Future investigations evaluating knee- versus hip-dominant exercise exposure and unilateral versus bilateral training strategies may improve understanding of factors associated with hamstring injury risk in baseball athletes.

4.4. Limitations

The MLB HITS database relies on manually entered information, and thus it is possible that there were errors in data entry. The present study evaluated only in-game injuries and did not include practice or training-related events. Exposure intensity metrics such as sprint frequency, acceleration demands, or training workloads were unavailable within the HITS database, and therefore, the findings should be interpreted with a degree of caution. Because most players were right-handed throwers, contralateral and left-sided injury analyses were not statistically independent. Age data was not collapsed to increase injury frequencies. The age 40+ cohort had a limited sample size indicating the potential of greater resistance to injury or attrition in the age cohort to signify the difficulty in competing past 39 years old. Therefore, interpretations involving older age groups, particularly athletes older than 40 years, should be approached with greater caution, as these unknowns must be acknowledged, and future study is warranted to further examine risk detection in

professional baseball players at an advanced age. The study only evaluated in-game data and therefore the present findings are not generalizable to other investigations that included both game and non-game events. In the future, further study of hamstring injury laterality including practice mechanisms is warranted. To best understand injury incidence and given the length of time between injuries, we have included both injuries and reinjuries within our study, which could bias the results as reinjuries may differ from primary injuries. Unfortunately, this data source does not allow us to fully evaluate those effects as many players could have suffered hamstring injuries before entering the league. Thus, all injuries were included and considered equally. Other limitations in the data include: (i) inclusion of recurrent injuries without separation from primary events; (ii) absence of training/practice-related injuries (in-game only); (iii) lack of measures of exposure intensity (e.g., sprints attempted) beyond games played; (iv) the dependency between right/left and contralateral/ipsilateral analyses noted above, and (v) infield positions outside of first base requiring players to throw right-handed that influence results pertaining to contralateral/ipsilateral interpretation.

Past studies indicate a successive increase in hamstring baseball injuries in the current decade with the majority occurring in the early part of the season from sprinting between home plate and first base and resulting in Grade 2 biceps femoris strains [13]. The current study builds upon existing knowledge and provides new insights across all positions in terms of better understanding lateralized injury surveillance, as although more injuries occurred to the left leg, the distribution of hamstring injuries between legs from a contralateral or ipsilateral perspective relative to the throwing arm were not significantly different. Significant differences in hamstring injury epidemiology were seen across positions, as younger outfielders were most at risk, and overall, the early season presents the highest risk.

Future investigations may evaluate whether eccentric force production characteristics, interlimb power asymmetries, and specific training modalities are associated with hamstring injury risk in professional baseball. As suggestions, research integrating dynamometry that assesses semitendinosus and semimembranosus strength in shortened positions, biceps femoris strength in lengthened positions, force plate metrics capturing muscle power, contractile properties and fatigue, GPS tracking for sprint distance, accelerations and limb preferences could elicit greater understanding of how to monitor factors associated with hamstring strain risk.

5. Conclusions

No statistically significant hamstring injury asymmetries were identified among major league baseball players despite biomechanical theories suggesting potential differences in lower-limb loading during baseball activities. Younger athletes demonstrated greater injury susceptibility, highlighting the need for future investigation into factors that may contribute to elevated injury incidence in younger professional baseball players.

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